HIGH EFFICIENCY SPACE SOLAR POWER CONVERSION SYSTEM

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ABSTRACT

The solar cell industry has continuously sought to increase efficiency of solar power systems. In addition to materials and processes, stacking of solar cells by either epitaxial growth or mechanical means has been utilized to convert more of the solar spectrum to electrical energy. Spectrum splitting was originally proposed in the 1950's to allow each of several cell types to operate in that part of the solar spectrum where the cell was most efficient. At that point in time selection of solar cells was limited and dichroic filters were proposed as the spectrum splitting technique.

The current effort described in this paper is a modification of this original concept which takes advantage of advanced solar cell technology. The initial testing of the concept reported here uses prisms as the spectrum splitting device since it is believed that dichroic filters do not have the capability to handle highly concentrated solar power. The initial testing reported in this paper was undertaken using the JPL large area pulsed solar simulator. This initial data suggests that efficiencies above 50% are possible with the spectrum splitting approach. Evaluations are continuing using solar concentrators.

INTRODUCTION

Solar cells are a highly desirable method of converting solar energy to electricity in space and consequently power all types of spacecraft. The principal drawbacks of the system are cost and mass. State of the art solar arrays utilize a limited portion of the solar spectrum since a solar cell can generate electricity only if the energy of the incident radiation is greater than the bandgap of the semiconductor.

Modification of the structure of solar cells to make them partially transparent to solar radiation allows cells with dissimilar bandgaps to be stacked atop one another. This vertically stacked array can be used with or without concentration, requires no spectral filter and allows wavelengths not convertible by the upper cell to be used by the lower cells. This approach is nearing space demonstration with the SCARLET solar array being developed by BMDO, NASA-LeRC and JPL for the New Millennium program.[1]

The alternative to vertical stacking of cells is spectrum splitting which allows each solar cell type to be placed in that portion of the spectrum where it has highest efficiency. This approach was initially proposed by Jackson in 1955 as a method to increase solar system efficiency.[2] The approach was further evaluated by Blocker[3] and a space array concept discussed by Becky and Blocker.[4] These studies suggested that high array efficiencies were attainable, however, the optical system proposed and the assumptions on cell efficiency caused the mass efficiency of the system to suffer to the extent that the system was superior to a planar array, but not revolutionary.

JPL personnel re-examined the concept using performance measurements on real solar cells which were derated to account for stages of development and real material issues.[5] This effort examined system costs, optics issues, spectrum splitting issues, cell string length issues, number of cell types and overall merit compared to other systems. This effort concluded that system merit is very sensitive to component parameters, but did offer efficiencies in the 40% range based on a dichroic splitter approach and moderate solar concentration. The approach also offers the widest possible scope of material choices, reduced cell temperatures and allows substitution of improved cells as they are developed.

Based on the lack of data on dichroic filters and their apparent limitation with regard to solar concentration, the experimental effort focused on prism splitting techniques with the recognition that mass issues would have to be seriously addressed. This paper reports the results of the initial experimental evaluation of this effort.

APPROACH

The data presented in this paper was obtained using the Large Area Pulsed Solar Simulator (LAPSS).[6] This system was designed to illuminate and measure the electrical performance of photovoltaic devices. It produces a 2-ms light pulse from two Xenon flash lamps which are adjustable over a wide intensity range without altering the chosen spectral irradiance. The LAPSS data-acquisition system acquires a full current-voltage characteristic curve of both the test solar cell and a reference solar cell during a single light pulse. Irradiance uniformity is +/- 2% and measurement repeatability is better than +/- 0.3 %.

The tests reported in this paper were done without any concentration mechanisms and relied solely on flashtube to prism distance to obtain solar intensity increases.

The prisms used for the initial testing reported in this paper were very low cost uncoated and contaminated glass with an internal transmittance of 70%. This is in contrast to the prisms now in use which are coated and have a transmittance of 99+%.

The first test undertaken was to assure that the rainbows from multiple prisms could be adequately superimposed. This was driven by the mass issue and the obvious fact that two half inch prisms weigh half as much as one, one inch prism. The rainbow produced as a result of overlapping the individual rainbows of 6 prisms is shown in

Figure 1.This rainbow was satisfactory for the purpose of irradiation of solar cells and could be adjusted in width by changing the prism stack to solar cell distance. This distance, for the 2 cm cells used in this investigation, was approximately 6 feet.

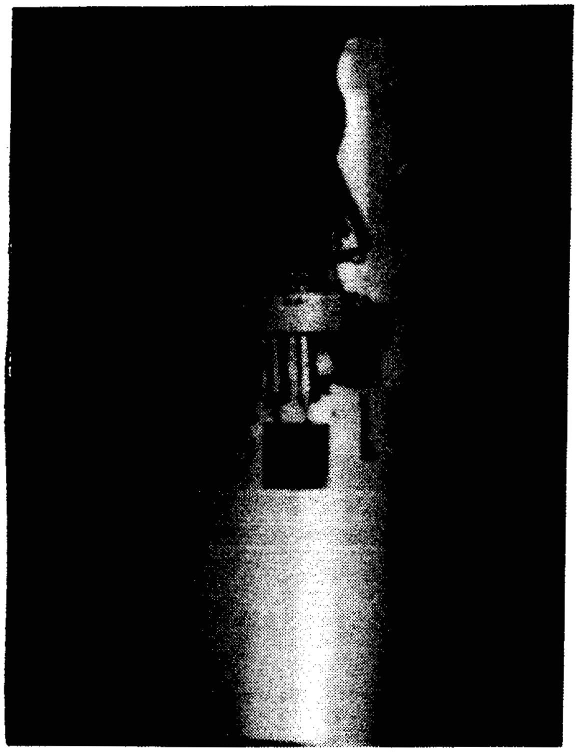

Figure 1. Rainbow produced by low cost prisms.

The solar cells were manufactured with a metallized rear surface as one of the electrical contacts. The second contact was a front surface buss bar. None of the cells were tested with a cover glass. The cell holder is shown in Figure 2. The holder was mounted on a linear motion system and solar cell performance measured at one cm intervals across the rainbow.

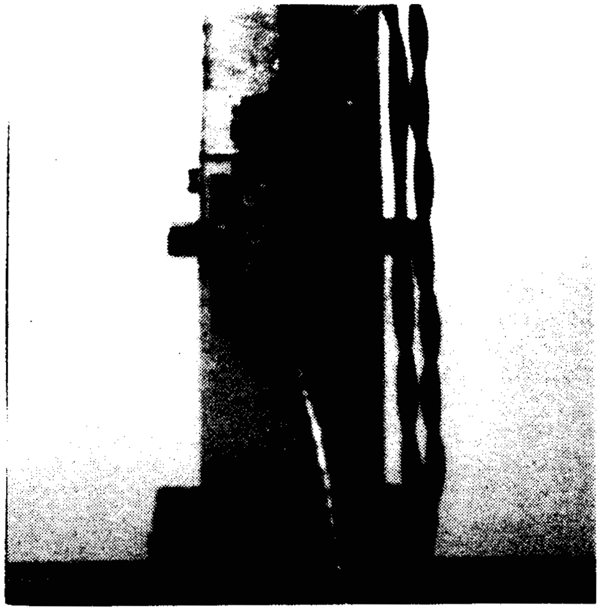

Figure 2. Solar cell holder mounted on linear motion system.

TEST RESULTS

The cells tested were a mix of cells several years old and not representative of current technology and cells procured for the test. All solar cells were 2 X 2 cm, except the GaP cell which was 2 X 2 mm. The results of testing are presented in Figure 3.

The prism to solar cell distance was adjusted to produce a rainbow measuring 6 cm from the green/blue boundary to the red/IR boundary.

The shape and location of the efficiency curves are in sharp contrast to the assumptions made in earlier studies which were that the efficiency was maximum at the band gap energy and decreased rapidly at higher energies. The peak efficiency of the solar cells is well removed from the band gap energy. This preliminary data also suggests that the higher efficiency solar cells (GaAs & Si) have a sharper peak than the lower efficiency solar

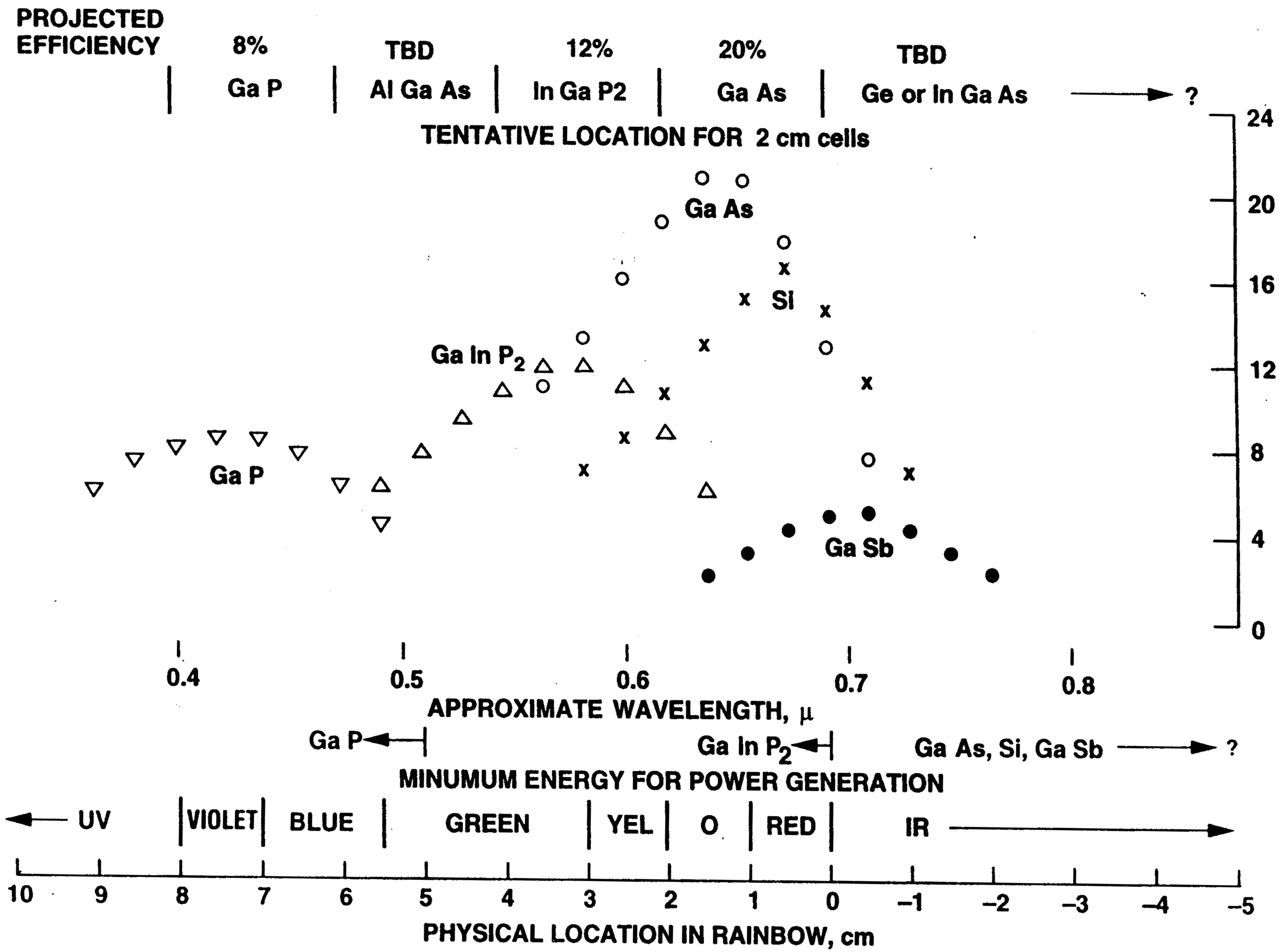

Figure 3. Solar Cell Efficiency as a Function of Location in the Rainbow.

cells.

The second major point to be made relative to the data is the efficiency is a corrected efficiency which is a result of the test system geometry. The Xenon flash tube in the solar simulator is 10 inches long and the prism stack was placed approximately 7 feet from the flash tube. This resulted in a wide spread of the rainbow which will not occur with a trough concentrator based system. Thus, the efficiencies are corrected for this reduced light intensity assuming a linear relationship between intensity and efficiency.

CELL TYPE	BAND GAP, EV	CONVERSION EFFICIENCY, %
GaP	2.48	8
AlGaAs	1.94	7
$InGaP_2$	1.77	12
GaAs	1.43	20
InGaAs	0.74	9
InGaAs	0.62	6
System Total		62

Figure 4. Estimated rainbow system efficiency.

The overall estimated efficiency is shown in Figure 4 using a 6 cell array. These numbers are based on no cover glass and direct contact with the buss bar on the cell surfaces. These numbers also used 70% efficient prisms rather than the optical quality 99+% prisms. The cell types selected for this proposed array is also shown at the top of Figure 3, which also proposes the physical location of the cells within the rainbow. This array size appears to result in a overall system efficiency which appears to be near the maximum obtainable with the spectrum splitter concept presented in this paper. Application of the system to terrestrial power generation could result in trading off some efficiency for reduced costs by selecting lower cost cells (GaAs replaced by Si) or eliminating some of the cell types used and increasing the width of the cells retained in the array.

SUMMARY

The use of a prism spectrum approach to increase solar cell system efficiency appears promising based on the preliminary data gathered to date. The approach also offers the possibility of reducing system costs, since the cost of solar cells is commonly the highest cost component of the system. Much higher concentration ratios for the system compared to a white light system appear feasible based on the reduced amounts of heat generated resulting in reduced cell temperatures.

While the data presented here are encouraging, end-to-end system testing to measure actual efficiencies is required to verify the estimates of efficiency presented here. Design and fabrication of such a system is being initiated to produce the needed verification of performance and to further understand the characteristics of the power conversion concept.

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